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APPLICATION OF THEMATIC MAPPING TECHNIQUES IN TERRAIN ANALYSIS.(U)
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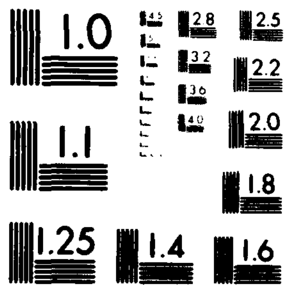

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The mission to support the Department of Defense (DoD) with terrain information has recently become the responsibility of the Defense Mapping Agency (DMA). The techniques employed to produce data bases of terrain conditions and the synthesizing of this data base information into terrain analysis products are critical in supporting mission requirements. Thematic mapping procedures provide the mechanism by which remote sensors, interpretation techniques, thematic subjects, data analysis techniques, and products can be examined in terms of production feasibility and capabilities.

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APPLICATION OF THEMATIC MAPPING TECHNIQUES IN TERRAIN ANALYSIS

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BIOGRAPHICAL SKETCH

Theodore W. Howard is a Supervisory Physical Scientist at the Defense Mapping Agency Hydrographic/Topographic Center where he serves as a researcher, consultant, senior scientist, and supervisor for the Terrain Analysis Mission recently acquired by the Center. He is responsible for the development and integration of new and improved methods, techniques, and procedures for the identification, analysis, and interpretation of terrain information as well as how predicting this information may affect military operations. Mr. Howard received his B.A. in Geography from Morgan State University, graduate certificates in Research and Development Management and Management Information Systems, and a M.S. in Technology of Management from American University. Currently, he is involved in the development of new products and techniques required to support the Terrain Analysis Mission of the Defense Mapping Agency. Mr. Howard is a member of the Association of American Geographers and the American Society of Photogrammetry.

ABSTRACT

The mission to support the Department of Defense (DoD) with terrain information has recently become the responsibility of the Defense Mapping Agency (DMA). The techniques employed to produce data bases of terrain conditions and the synthesizing of this data base information into terrain analysis products are critical in supporting mission requirements. Thematic mapping procedures provide the mechanism by which remote sensors, interpretation techniques, thematic subjects, data analysis techniques, and products can be examined in terms of production feasibility and capabilities.

INTRODUCTION

On June 25, 1979 the Secretary of Defense approved the transfer of the responsibility for supporting DoD with terrain analysis information from the Defense Intelligence Agency to DMA. As a result, DMA initiated the Terrain Analysis Program (TAP) which is designed to provide the military with terrain analysis information in cartographic (map) and digital formats. TAP constitutes a new mission for DMA and it will be treated as an extension of the DoD mapping, charting, and geodetic program.

For several years military tacticians and weapons developers have expressed a growing need for tactical-level terrain information. One example which proved this point was the 1973 Arab-Israeli war, where the operational effectiveness of men and equipment depended heavily upon the terrain. Accurate assessments of how the terrain influences ground mobility and visibility are critical in the planning and execution of successful military operations. As outlined in the military training doctrine, the availability of reliable, current terrain information in quantitative terms is required to make quantitative predictions in a fast-moving, time-dependent environment. The amount of time available to field commanders and their staffs does not allow for raw terrain data to be analyzed. Consequently, terrain data in many instances must be generated in advance, evaluated as to its affect on equipment and military operations, and provided to the commander in a format which is easily read and understood.

A wide range of terrain analysis products is envisioned for military use:

Road and bridge maps showing current availability, capacities, conditions, dimensions, etc.

Cross-country movement (CCM) speed-prediction maps for specified types of vehicles and foot troops showing avenues of approach, obstacles, inland hydrographic features, etc.

Intervisibility assessment maps showing potential for cover and concealment, line-of-sight, and fields-of-fire.

Combat engineering maps identifying areas of available engineering materials.

Coast and landing beach maps depicting landing sites, cross-country movement potential, etc.

Urban area analyses evaluating built-up areas for military operations.

Ground sensor/mine emplacement maps specifying the suitability of the terrain and the expected effectiveness of sensors and mine deployment.

Digital terrain information to support war gaming simulated training exercises.

With such maps or digital data, the commander and his staff can spend their limited time identifying and selecting among their planning options in light of other combat-related information and experience, rather than collecting and analyzing a minimal set of raw terrain decision data needed to solve a particular combat problem.

The question now becomes: How can DMA support these requirements for reliable, quantitative, and timely terrain information? An approach currently in operation utilizes a technique initially developed by the U.S. Army Engineer Topographic Laboratories (USAETL) located at Fort Belvoir, Virginia.

DMA's approach involves quantifying terrain data through the application of thematic mapping techniques so that data can be mapped using available photographic and textual resources, evaluated through quantitative effect modeling techniques developed by the USAETL and the Waterways Experiment Station (WES) located at Vicksburg, Mississippi, and portrayed quantitatively. The basic technology to perform all of these operations exists within DMA and has been demonstrated in many instances in support of past terrain analysis requirements. However, continued effort is required by the R&D laboratories, DMA, and formulators of military doctrine in meeting the terrain information requirements of the modern-day battlefield.

This paper covers the application of thematic mapping techniques in support of terrain analysis requirements, specifically examining terrain information acquisition capabilities. First, a description of a thematic map and a terrain analysis product is given. Simply stated, a thematic map is a map which has a specific theme. It may be, for example, a soils, vegetation, geologic, or surface drainage map. Terrain analysis is defined as the process of analyzing a geographical area to determine the effect of the natural and manmade features on military operations. It also includes the influence of climate on those features.

TERRAIN INFORMATION ACQUISITION CAPABILITIES

A report published by USAETL entitled "Remote Sensor Image Capabilities for Acquisition of Terrain Information" points out that a quantitative measurement process has been needed for many years to obtain information from the various types of remote sensor imagery, both within the military and in private industry. The reasons for the lack of such a measurement capacity are summarized as due to the extreme costs involved with the difficulty in obtaining test groups of well-trained image interpreters.[1] Consequently, USAETL initiated an investigation to assess sensor capabilities. Approximately 4,000 data elements were identified as being needed to support the production of standard maps. Of this requirement, a random sample of some 1,592 data elements was divided into major data fields and evaluated based upon a coding system (Table 1). The summary of the remote sensor imagery evaluations (Table 2) indicates that of the total data elements evaluated, 40 percent were evaluated as Code A, 5 percent as Code B, 38 percent as Code C, 17 percent as Code D, 13 percent in mensuration Category 1, and 10 percent in Category 2.[2] This indicates that a considerable amount of terrain information can be acquired through judicious utilization of remote sensor imagery assuming that the interpreter has available collateral materials, and stereo viewing and mensuration equipment. It can also be assumed that one or more types of remote sensor imagery are available, such as black-and-white photography, thermal infrared, radar, multispectral, etc.

Table 1. Summary of Remote Sensor Imagery (RSI) Capability Codes

Code	Definition
A	Data element can be obtained from RSI.
B	Data element cannot presently be obtained from RSI.
C	Partial information obtainable.
D	Other collection methods required.
E	Data element not compatible with RSI methods.
1	Measurements in two directions required.
2	Measurements in three directions required.

Based upon these evaluations, it can be seen clearly that a terrain analyst, well-trained in photointerpretation techniques, can employ remote sensor data to produce thematic information. DMA has incorporated remote sensor technology and interpretation techniques with a unique approach to the generation of thematic data. This approach involves the utilization of terrain analysis teams in the production process. Each team is composed of eight well-trained analysts, all with interdisciplinary backgrounds and each with specialized training or experience in one or more of the following fields: forestry, geology/soils, hydrography, cartography, geography, engineering, urban planning, and meteorology. Consequently, a synergistic effect is produced whereby the constant interrelationships, exchange of knowledge, and team effort in problem solving in many instances provide results which are greater than the sum of the individual contributions.

DATA BASE DEVELOPMENT

As inferred in the introduction, it is the field and/or weapons systems requirement for terrain information that drives the technological and techniques development programs. This also holds true in the development of a data base. The requirement for terrain information will ultimately determine what data elements should make up a data base. The problem becomes: Which data are cost effective and feasible to generate in a production environment? Currently, DMA has two data base development programs underway, one of which is an internal production Terrain Analysis Data Base (TADB) and the other is a user

oriented digital Land Combat Data Base (LCDB), each composed of thematic data.

Table 2. Summary of Remote Sensor Imagery Evaluation

DATA FIELD	NUMBER OF ELEMENTS FROM RSI	REMOTE SENSOR CAPABILITY CODE* A NO.	A %	B NO.	B %	C NO.	C %	D NO.	D %	1 NO.	1 %	2 NO.	2 %
AIR TERMINALS/ LANDING ZONES	97	76	78	11	12	10	10	0	0	24	25	16	16
BUILDINGS/STRUCTURES	113	53	47	36	32	24	21	0	0	20	18	18	16
COASTS/LANDING ZONES	45	22	49	0	0	23	51	0	0	11	24	11	24
ELECTRIC POWER	111	40	36	13	12	41	37	17	15	8	7	16	14
GROUND WATER	102	1	10	10	10	31	30	60	59	7	7	6	6
HYDROLOGY/DRAINAGE	148	90	61	1	1	51	34	6	0	31	21	32	22
PIPELINES	83	9	11	5	6	64	77	5	6	9	11	8	10
RAILROADS	37	37	100	0	0	0	0	0	0	6	16	2	5
ROADS/TRAILS	34	28	82	0	0	6	18	0	0	8	24	1	3
MANUFACTURING PLANTS	53	10	19	0	0	39	74	4	8	2	4	1	2
MILITARY INSTALLATIONS	125	61	48	4	3	60	49	0	0	39	31	5	4
PORTS/HARBORS	107	56	52	0	0	51	48	0	0	29	27	6	6
ROCK TYPE	50	5	10	0	0	42	84	3	6	3	6	7	14
SETTLEMENTS	275	100	36	0	0	95	34	80	30	11	4	5	2
SURFACE CONFIGURATION	29	23	79	0	0	5	17	1	3	2	7	10	34
SURFACE MATERIALS	80	8	10	2	2	16	20	54	68	1	1	6	7
VEGETATION	19	8	47	0	0	11	53	0	0	0	0	7	39
WEATHER/CLIMATE	84	14	17	0	0	34	40	36	43	0	0	1	1
TOTALS	1592	641	40	82	5	603	38	266	17	212	13	160	10

*Evaluation Code E not considered in this summary due to the incapability of RSI to depict the data elements.

The TADB, a cartographic/digital, multiproduct data base, will be comprised of real variable data elements subdivided into thematic data fields (Table 3). As presently envisioned, the TADB will be flexible enough such that it could be formatted on a cell-by-cell basis (specified cell size) or in vector format wherein all the header, feature code, and attribute data for a particular feature are followed by the point line or area outline coordinates pertaining to the feature being analyzed. A one-to-one exchange of data elements with other data bases within DMA and the outside community is also necessary. However, attempts to give a unique number to each feature, attribute, and text descriptor which contain real variable data, a one-to-one exchange mechanism with other data bases, have been difficult tasks. The advantages of unique work coding allow

great flexibility in formatting the data, attributes can overlap each other, and multiple features of a similar data field within the minimum cell size can be accommodated.

Because of the various military users' demand on available production resources, DMA realized a need to standardize a data base that will support a multiplicity of digital terrain information requirements. As a result, the LCDB was established to standardize data content, format, and accuracy among the various users. Data elements were examined for their relative importance, compatibility between systems, applicability for digitization, and ease of collection. Three levels of detail were formulated to serve anticipated requirements for thematic data. Level I is suggested to satisfy requirements for upper echelon planning, generalized line-of-sight and on-road movement determinations, and most map background display and terrain view applications. Level II will satisfy the requirement for detailed movement and intervisibility analyses. And, Level III is intended primarily for those combat modelers interested in very dense and detailed data over small areas. The LCDB summary (Table 4) lists those data elements included in each level of detail.

Table 3. Terrain Analysis Data Base

Thematic Data Field	Data Element*
Vegetation	Type
	Canopy
	Height
	Spacing
	Stem diameter
	Land use
	Suitability for construction
	Seasonal variations
	Crown diameter
	Heights of lowest branches
	Undergrowth
Surface Configuration	Surface slope
	Direction of slope
	Slope intercept
Obstacles	Type
	Slope
	Height
	Width
Hydrography	Bottom materials
	Bank characteristics
	Velocity
	Width
	Depth
	Flood plain limits
	Fording sites
Soils/Geology	Type
	Texture
	Soil group
	Degree of stoniness
	Depth to bedrock
	Mines, pits, quarries
	Geologic profiles
	Cross-sections
	Special features
	Surface roughness
Road/Bridges/Railroads	Type
	Width
	Surface material
	Length
	Construction material
	Load classification
	Clearance
	Gauge
	No. of tracks

*Data to include all feature attributes in real data format.

Table 4. Land Combat Data Base Summary

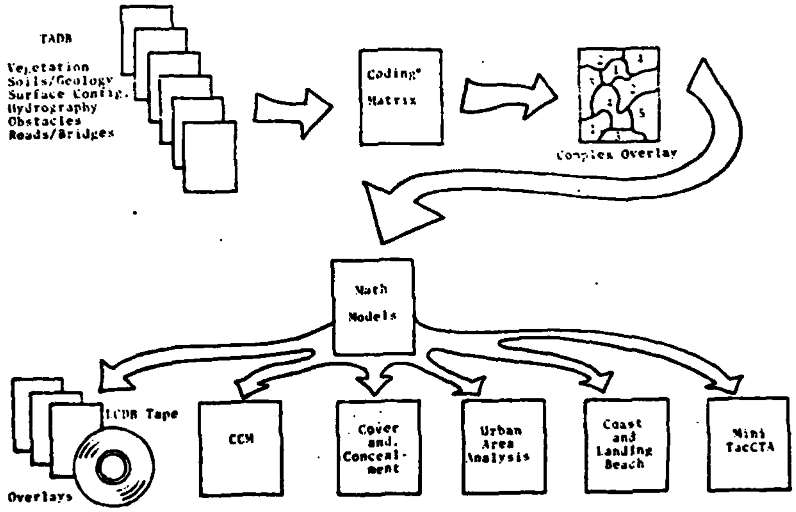
Thematic Data Field	Data Element	Level of Detail
Surface Configuration:	Elevation	I, II, III
	Slope Intercept Factor	I, II, III
Surface Features:	Type	I, II, III
	Ave. Height	II, III
	Ave. Canopy closure	II, III
	Ave. Canopy closure (winter)	III
	Ave. Crown diameter	III
	Ave. Stem diameter	II, III
	Ave. Stem spacing	II, III
	Ave. Lowest branch	III
	Undergrowth	II, III
Surface Materials:	Type	II, III
	Qualifier	II, III
	Surface Roughness Factor	II, III
	Depth of Surface Material	III
	Depth to Bedrock	III
Hydrography:	Type	I, II, III
	Gap width (ave.)	I, II, III
	Velocity (high)	III
	Velocity (ave.)	II, III
	Velocity (low)	III
	Water depth (high)	III
	Water depth (ave.)	II, III
	Water depth (low)	III
	Bottom composition	III
Movement:	Road weatherability	I, II, III
	Road surface	II, III
	Road width	I, II, III
	Road grades	III
	Road curve radius	III
	Railroad tracks	I, II, III
	Railroad gage	III
	Railroad electrification	III
	Road/Railroad capacity	III
	Bridge classification	I, II, III
	Bridge class. reliability	I, II, III
	Bridge bypass	III
	Bridge spans	III
	Bridge horizontal clearance	III
	Bridge construction material	III
	Overhead clearance	III
	Airfield Runway surface	I, II, III
	Airfield Runway width	III
	Airfield Runway length	III
Other Features:	Linear features	II, III
	Linear features height	II, III
	Linear features slope	II, III
	Vertical features	II, III
	Vertical features height	II, III
	Other features	II, III

At this point, it is important to reemphasize the nature and intent of the data bases under development. The TADB is a cost-effective production mechanism for housing all the data elements required to support a multiplicity of both cartographic and digital users. The LCDB is a digital, user-oriented extension of the TADB. Even though the TADB will allow for the storage and retrieval of more specific and quantified thematic data, only the data that are cost effective in terms of production processes will be incorporated.

THEMATIC DATA PRODUCTION AND ANALYSIS TECHNIQUES

The production of thematic data is accomplished through the analysis of remote sensor imagery by an operational team of terrain analysts familiar with the characteristics and capabilties of remote sensor systems. Utilizing a systematic approach to photointerpretation, textual data analysis, and topographic data analysis techniques, the team is able to produce detailed terrain information as mentioned in the TADB and LCDB. The terrain information is generally produced at a map scale of 1:50,000 in overlay format. This scale satisfies the majority of the requirements levied for tactical terrain data. The positional accuracy of the data is relative to the base on which they are portrayed. The level of detail and accuracy of the analyzed data are contingent upon the scale and resolution of the imagery evaluated. However, the data produced generally fall within an 80- to 90-percent level of confidence. Mensurated data accuracies are within a ± 2 meters as it relates to a specific feature.

Once the thematic data base has been compiled, the data are processed through a product synthesization procedure (Figure 1). In general, this process involves using the thematic data overlays of the TADB which portray coded terrain conditions, stacking one on the other and using a clear piece of overlay material to compile a complex overlay. The complex overlay is merely a coded representation of all the terrain conditions that exist on the thematic data overlays portrayed on one overlay. This overlay becomes the base from which a package of products can be generated. Mathematical models are applied to the quantified data on the complex overlay enabling predictions to be calculated concerning cross-country movement speeds, fields-of-fire, line-of-sight, probability of detection, horizontal visibility, and cover and concealment.



*The coding matrix is a coding table for those data elements which are depicted when the thematic overlays (TADB) are stacked. The coding matrix defines the code used on the complex overlay.

Figure 1. Synthesis process.

For example, the model for cross-country movement requires five factors that exercise a significant influence on the speed of vehicles moving cross-country: soil, slope, vegetation, microrelief, and slope intercepts. The underlying premise of the model is that the maximum operational speed of a vehicle is attained under optimum conditions on a firm, smooth, flat surface. As conditions depart from the optimum, the speed is diminished by an amount proportional to the degree of departure from the optimum. Water courses and visibility also

influence speed but are not incorporated into the model because drainage crossings and visibility conditions are route dependent and weather dependent, respectively. The general case model is illustrated in Figure 2. This process of using models to synthesize terrain analysis information is quite complex and deserves a detailed description in another paper.

1. S_1 = Speed prediction based on influence of slope alone

$$S_1 = \text{MPH} = \frac{60 - \text{slope}}{1.2}$$

2. S_2 = Speed after consideration of vegetation

S_2 = S_1 multiplied by F_1 or F_2 and .5

$$F_1 = \frac{\text{Stem spacing} - \text{Stem diameter (in meter)}}{1.6}$$

if $F_1 > 1$, $S_2 = (S_1)(F_1)(.5)$

any minus value for F_1 indicates a standstill

if $0 < F_1 < 1$ find & use F_2

$F_2 = F_1 - \frac{\text{Stem diameter in meters.}}{.04}$ Any minus value for F_2 indicates a standstill

$$S_2 = (S_1)(F_2)(.5)$$

3. S_3 = Speed after consideration of soil strength (RCI)

$$S_3 = (S_2)(F_3)$$

$$F_3 = \frac{\text{RCI} - 30}{30}$$

4. S_4 = Speed after consideration of micro-relief (surface roughness)

$$S_4 = (S_3)(F_4)$$

$$F_4 = \frac{100 - \frac{2\,(\text{Obst height, cm}) + (\text{Approach angle, degrees})}{(\text{Obst spacing in meters})}}{100}$$

5. S_5 = Speed after consideration of slope intercept frequency

$$S_5 = (S_4)(F_5)$$

$F_5 = \frac{280 - \text{intercept frequency}}{280} = S_5$ (final speed prediction)

Figure 2. Speed prediction model.

PRODUCT CONCEPTS

Thematic mapping techniques in the preparation of terrain analysis products are a reasonably uncomplicated mechanism for handling complex terrain data. Through the establishment of thematic data structures, terrain data can be quantified and processed in either a manual or digital mode, enabling production to be generated using a mix of thematic data files.

It is the intent of DMA that a package of standardized terrain analysis products be developed. These products will provide users with the necessary terrain information to plan and execute successful military operations. This product development program is also underway and will address development of those products referenced in Figure 1. Now, the task is to produce terrain analysis information in an easily extractable and interpretable format. The design and information content of these products will be based on system requirements. Each requires the application of technologies and techniques that will insure reasonable data content accuracies. The success of DMA's Terrain Analysis Program depends heavily on the continued application of a thematic mapping approach to terrain information production and analysis through the use of image processing, remote sensing, data processing, and data management technologies. Efforts to define and refine data bases of terrain information, data manipulation strategies, and products are an ambitious undertaking. However, it is anticipated that much of the effort will be completed within several years.

SUMMARY

In summary, an operational procedure for supporting the Terrain Analysis Program has been established through the implementation of a thematic mapping approach to the production and analysis of terrain information. Data bases of terrain conditions are being developed to support a multiplicity of users. From these data bases, standardized terrain analysis products will be developed.

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